1999 Annual Report of the Hatches Harbor Salt Marsh Restoration Project

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Introduction

After 12 years of planning and interagency negotiation, and three years of pre-treatment monitoring, CACO began a program in 1999 to restore 60-90 acres of salt marsh habitat at Hatches Harbor (Provincetown). Since 1930 a dike has bisected the original 200-ha salt marsh, thereby reducing flooding heights and salinity, restricting fish access and allowing the replacement of salt marsh cord grass and salt hay (*Spartina alterniflora* and *S. patens*) by common reed (*Phragmites australis*) and other salt-intolerant plants. Restoration comprises the installation of enlarged culverts (NRPP-funded) and their gradual opening, coupled with annual monitoring of tide heights, surface water and porewater quality, halophyte production, habitat use by birds, fish and shellfish, and nuisance mosquitoes. The choice of monitoring variables was based upon hypothesized changes to the system once tidal flow was restored. Importantly, the extent of tidal restoration is constrained by the presence of the Provincetown Municipal Airport within the flood plain. Cooperating agencies include the Federal Aviation Administration, Massachusetts Department of Environmental Protection, Massachusetts Aeronautics Commission, Cape Cod Commission, Provincetown Airport Commission and the Provincetown Center for Coastal Studies.

The four 3-ft high by 7-ft wide culverts replaced an original 2-ft-diameter circular culvert. Two of the four new culverts were opened 10 cm in May 1999, thereby doubling the cross-sectional area available for tidal exchange. A series of transects were established in the marsh basin along which vegetative cover and porewater quality were monitored (Figure 1).

<u>Tide Heights and Tidal Range</u>

A primary monitoring effort is to track changes in water level during a tidal cycle (tide stage) in both the restricted and unrestricted marsh. Water level in salt marshes is a good proxy for sediment chemistry (Portnoy & Valiela 1997), the extent of inundation, penetration of saline water into the peat soils and the degree to which the marsh peats dewater during low tide (Montague et al 1987). All of these factors affect the persistence of invasive plant species, productivity in stands of *Spartina* (Steever et al 1976; Odum et al 1995), water quality in the restricted marsh and the species composition and abudance of mosquitoes.

Hydrodynamic modeling in the Hatches Harbor system (Roman et al 1995) has shown that tidal exchange is driven by differences in hydraulic head between the basins, the volume of the restricted marsh and the size, shape and elevation of the culverts. Of equal importance is the elevation of the bottom of the culvert, as this determines how much of the tidal prism remains at this level during an ebbing tide. It is important to maximize the amount of the culvert cross-sectional area that is nearest this critical elevation. This would maximize the extent of dewatering during ebb tides. Such dewatering helps encourage re-establishment of native cord grass stands.

The interaction between increased tidal inundation, due to a larger culvert, and the culvert shape will affect tidal changes in observed water levels in the restricted marsh. Discrete events (storms, breaches in the spit at the outer mouth of the harbor, etc.) can also cause transient changes in water level. These episodic events can be important if they occur during a ecologically critical periods, for example, the peak of the growing season.

Methods

Two multi-parameter data loggers (YSI UPG6000, Yellow Springs, OH) were deployed in both the restricted and unrestricted marsh on either side of the culvert approximately 0.7 – 0.9 m (2 – 2.5 ft) above the bottom. Data loggers measured water levels with on-board pressure transducers that compensated for salinity and temperature. Tide stage was continuously recorded ten times an hour for two-week periods. Sampling commenced in October 1998 and continues to the present day. Tidal range was calculated for both morning and afternoon tides by subtracting average low tide levels from high tide levels. Tidal range comparisons were made among spring tides. The effect of weather and lunar cycles were compared to tide stage and water levels.

Results and Discussion

The tidal restriction causes tidal stage above and below the dike to differ (Figure 2). Consecutive high and low tides in the unrestricted marsh were more equal in height in the unrestricted marsh. Additionally, morning and evening tide heights differ more in the unrestricted than in the restricted marsh. These qualitative differences arise from the old culvert that filtered out or shifted one or more of the tidal components of the flooding tide. These tidal offsets can alter the hydroperiod in a tidally restricted marsh and change natural tidal flooding regimes.

Overall tidal range has increased by 22 – 28% in the restricted marsh since the new culvert was opened (Figure 3). This increase in tidal range is due mainly to significantly lower low tides as a consequence of the enlarged culvert opening. Culvert shape was also changed from a circular to a rectangular cross-section, shifting a greater portion of the cross-sectional area downward thereby allowing a longer ebb period for drainage.

The tidal stage record also shows that the new culverts effectively limit water levels in the restricted marsh during conditions that result in unusually high tides in the unrestricted marsh. On 23-24 November and again on 23-25 December, spring tides coincided with other astronomical conditions to produce the highest tides of the year (between 12.3 – 12.7 ft MLW, approximately 2 – 2.5 ft above normal spring tides). The restricted marsh water levels, in contrast never exceeded 9.6 ft MLW, approximately 0.4 ft MLW above normal spring tides (Figure 4). This corresponds to 16 - 20% of the excess tidal range in the unrestricted marsh. Thus the new culverts filtered out 80% of the increases in spring tide height. These findings corroborate the results of the hydrodynamic modeling that established the ability of the culvert design to filter transient events that cause extreme high tides.

Flooding Depth, Porewater Salinity And Sulfides Over A Spring-Neap Tidal Cycle

The species composition and morphology of coastal wetland vegetation is determined by site-specific salinity and flooding regimes. The absolute elevation relative to the local tidal range is a basic determinant of both the salinity and the flooding depth of salt marsh soils. Proximate causes of plant stress with prolonged seawater flooding include osmotic imbalance and sulfide toxicity, inhibiting nitrogen uptake. High porewater salinity and/or sulfide concentrations are stressful for all wetland plants, causing mortality in fresh-brackish species and stunted growth in typical salt marsh grasses (e.g. *Spartina alterniflora*).

The wetland surface immediately above the Hatches Harbor dike is about 15 cm below the elevation occupied by intertidal *S. alterniflora* in the unrestricted marsh seaward of the structure. This is an expected result of 1) reduced tidal range, allowing peat dewatering, aeration and collapse (Portnoy & Giblin 1997) and 2) decreased tidal transport of inorganic particles which in an unrestricted marsh accumulate on the wetland surface (Thom 1992). The relatively low elevation of the marsh surface relative to modern sea level indicated that flooding depths and durations might exceed those of the unrestricted marsh once tidal range is restored. Thus there was concern that excessive flooding and consequently high salinity and/or sulfide could hinder the re-establishment of salt marsh vegetative cover in the Hatches Harbor restoration site. This would occur if, during tidal restoration, flooding heights increase faster than the rate of sedimentation. During spring tides, flooding depth and duration behind the dike already exceeded those of the unrestricted natural marsh before any tidal restoration. This was because of the small (2-ft) diameter of the dike's original culvert, which impeded discharge during low tides.

To establish a basis for future assessments of the effects of increased tidal volume on wetland soil conditions, water depth and porewater salinity and sulfide were monitored along transects in both the restricted and the unrestricted dike. Pre-restoration monitoring was conducted in September 1997; post-restoration data, when the two tide gates were opened to a 10 cm height, were collected in September 1999.

Methods

Marsh water levels and porewater salinity and sulfide concentrations were measured during low tide (tide height seaward of the dike < 0.93 m-NGVD) along vegetation transects 7 and 2 located seaward and landward of the dike, respectively (Fig. 1). Sampling was conducted every 2-3 days with seven observation dates in 1997 and nine in 1999. All sampling was conducted between 15 September and 1 October in both years to coincide with reported fall maximum sulfide concentrations in New England salt marshes (Howarth & Teal 1979, Howes et al. 1983). Water levels were monitored in 60 cm long, 3-cm ID PVC well screens driven 50 cm below the marsh land surface, leaving 10 cm exposed. Elevations of casings were determined by differential leveling. Porewater for salinity and sulfide determinations was withdrawn from the sediment (10 cm depth) with a 2-mm ID stainless steel probe with slotted point; water was drawn into a 3-ml syringe fitted onto the probe's upper end. Salinity was determined using a refractometer. Total sulfides were determined colorimetrically (Cline 1969, detection limit 10 μM).

Results and Discussion

Flooding regime

The culverts installed at their present opening in 1999 (with two culverts open to 10 cm) about doubled the cross-sectional area available for discharge; in addition, all of this area is at an elevation (between 0.53 and 0.63 m-NGVD that optimized discharge at low tide. Thus at nearly all sampling stations, low-tide water levels during 1999 were below the peat surface even during spring tides (Fig. 5). This represents a major qualitative change since 1997: peat that was constantly waterlogged for about half the spring-neap cycle before restoration is now dewatered and aerated on each low tide. Increased aeration should benefit halophyte survival and production.

Salinity

In general, porewater salinity was consistently 30-34 ppt seaward of the dike, while porewater salinity above the dike ranged from 30 ppt near the creek bank to 0 ppt 140-160 m inland (Fig. 6).

The 1999 culvert openings caused root-zone salinity to increase significantly (ANOVA, $P<0.05$) along Transect 2 (Fig. 6), with brackish (1-7 ppt) porewater infiltrating plant communities that were strictly freshwater in 1997. Salinity increased all along the transect up to 140 m from the creek bank, with the 20 ppt concentration extending about 20 m further than in 1997. Increased salinity should over the long term suppress freshwater wetland and *Phragmites* growth favoring salt marsh grasses.

Sulfides

Sulfide concentrations in 1997 and 1999 were low and did not differ significantly along the monitored Transect 2 (Fig. 7). An increase in sulfides would be expected if salinity, providing abundant sulfate, and waterlogging, promoting anaerobic carbon catabolism by sulfate reduction, both increased. Although salinity significantly increased in 1999 (Fig. 6), so did drainage and aeration (Fig. 5), favoring aerobic decomposition and sulfide oxidation.

Adult Mosquitoes

With increased tide heights within the flood plain above the Hatches Harbor Dike, there is concern that floodwater mosquito breeding habitat may increase, thereby increasing mosquito production and the mosquito nuisance at the Provincetown Airport. As part of the interdisciplinary program of pre- and post-restoration monitoring, nuisance mosquito monitoring was undertaken to assess any changes in abundance and/or species composition that could in turn reflect changes in breeding habitat.

The abundance and species composition of nuisance mosquitoes depend in large part on wetland flooding regimes and salinity. On outer Cape Cod, summertime floodwater *Aedes* species comprise chiefly *A. canadensis* and *A. cinereus* emerging from freshwater and *A. sollicitans* and *A. cantator* from brackish or saltwater habitats; the latter species is particularly dominant in tidally restricted wetlands on the outer Cape (Portnoy 1984). *Coquilletidia perturbans* also breeds in freshwater but larvae develop only during winter in emergent wetlands; thus, adult abundance is less affected by episodic flooding than the summer-breeding *Aedes* spp.

Adult mosquito trapping was conducted during the summers of 1997, 1998 and 1999 to assess the present species composition and abundance of adult mosquitoes for comparison with post-restoration Hatches Harbor. Sampling was conducted using duplicate traps at three locations. The objective was to represent seasonal abundance and species composition over the entire flood plain using repeatable methods for comparison with future monitoring as tidal restoration proceeds. Species composition should indicate primary breeding habitats, especially with regard to those habitat variables that are most sensitive to changes in tidal flow through the Hatches Harbor Dike, such as salinity and wetland hydroperiod.

Methods

Duplicate Bioquip #2803 EVS mosquito traps baited with light and 500 g of dry ice were set 1.5 m above the ground at three locations within the Hatches Harbor flood plain during July and August of each year (Fig. 1). Trapping stations represented natural salt marsh ("seaward"), diked marsh ("taxiway"), and airport terminal, where mosquitoes were most likely to encounter and bite people. Traps were hung at about 1800 h (dusk) and retrieved at about 0600 h the following morning. Trapped adults were identified to species (Darsie & Ward 1981).

Results and Discussion

Adult mosquito abundance is primarily affected by precipitation, especially that occurring during the spring and summer when warm temperatures promote egg hatching and larval development. Thus all major species were much more abundant during 1998 when heavy precipitation occurred in spring and early summer than in the extremely dry summer of 1999. However, heavy rain in 1998 apparently favored some species more than others. *Aedes cantator* production was especially high in 1998, and almost nil in the drought year of 1999 (Fig. 8). Production of the salt marsh mosquito *Aedes sollicitans* appeared less sensitive to precipitation; this is expected given its tendency to breed in high-salinity tidal waters especially after spring tides.

Freshwater breeders were dominated by *Coquilletidia perturbans* (Fig. 8). Given this species's dependence on emergent marshes that remain flooded throughout the winter, *C. perturbans* likely emerged from wetlands outside the coastal flood plain, e.g. inter-dune ponds. If this were the case, its abundance would be unrelated to habitat changes at Hatches Harbor associated with the restoration.

Interannual variation in abundance at the three trapping locations was greatest for *Aedes cantator*, again reflecting its apparent dependence on high precipitation. Inter-site differences appear related to the proximity of appropriate breeding habitat with salt marsh species *(A. sollicitans)* generally more abundant at the dike and freshwater-breeding *Coquilletidia* most abundant at the airport terminal, which is nearly surrounded by freshwater wetlands.

Bivalve population sampling

Bivalve beds are found in much of Hatches Harbor within the intertidal and shallow subtidal zone. These beds represent a significant resource to the Town of Provincetown. They are used as seeding beds where seeding clams are rotated out every three years to other beds where they are then grown out to market size. This part of the Hatches Harbor monitoring program grew out of a concern expressed by town officials that the change in tidal exchange produced by the restoration would disturb shellfish beds reducing harvests. Bivalve monitoring was started to identify and correct unintended impacts to bivalve beds arising from restoration and associated activities.

This monitoring consisted of annual sampling to document population levels of commercially important bivalves, the quahog (*Mercenaria mercenaria*), the steamer clam (*Mya arenaria*) and the blue mussel (*Mytilus edulis*) for comparison with later years.

Methods

Bivalve samples were collected in Hatches Harbor over a nine-day period from May 18 – July 21 1999. Nine stations, randomly selected, were placed on each side of the dike. At each station, a transect line was laid perpendicular to the main creek, parallel to the dike, and three 1m^2 quadrats were randomly located along this transect. A total of fifty-four samples were collected twenty-seven on each side of the dike.

Bivalves were harvested from each quadrat by collecting the sediment to a depth of 15 cm and sieving it through a 0.25-cm benthic sorting tray. Harvested bivalves were measured from the umbo to the edge of the shell using calipers and then returned to the creek bed sediments to the location and at the depth from which they were collected. Sediment samples were collected for grain size analysis at a later date. All species counts were compared to a benthic sample set collected in Hatches Harbor in 1997 using similar methods (E. Kinney, unpublished data).

Results

Quahogs, mussels and steamers were found in substantial numbers in the restricted marsh in 1999. However, bivalves in the unrestricted marsh were nearly absent as periodic harvesting had occurred earlier that year. As this harvesting will confound our attempts to discern demographic trends in the unrestricted marsh, all subsequent bivalve sampling will be conducted behind the dike.

Mussels were located only in the unrestricted marsh in 1997 and substantially more steamers were found in 1999. These two findings are likely a function of the larger effort and spatial extent of the 1999 study; unfortunately the 1997 study was too small to make statistical comparison between years possible. The number of bivalves of each species varied widely among quadrats. The total numbers for all quadrats are in Table 1. Size distribution of bivalves varied widely, even from one quadrat to the next (Table 2). Average quahog size was between seed and littleneck (Malouf 1991). The average steamer was one-third this size and the average mussel sizes were approximately double the quahog size.

Table 1. Total number of bivalves collected

Bivalve	Restricted marsh 1997	Restricted marsh 1999	Unrestricted marsh 1997
Quahog	78	186	16
Blue mussel	0	32	976
Steamer clam	10	177	11

Table 2. Average size of bivalves collected

Bivalve	Restricted marsh 1997 (in./mm)	Restricted marsh 1999 (in./mm)	Unrestricted marsh 1997 (in./mm)
Quahog	1.2 in. (30.6 mm)	1.5 in (38.3 mm)	1.3 in. (32.4 mm)
Blue mussel	0	2.1 in (53.4 mm)	2.7 in. (68.7 mm)
Steamer clam	0.4 in. (10.9 mm)	1.4 in (34.6 mm)	0.3 in. (7.1 mm)

The average number of bivalves per quadrat varies so widely that mean values do not reveal their patchy distribution. However, these average sizes and numbers per m^2 (Table 3) may give us a qualitative view of the distribution of these species. A modification of the t-test was used on the 1997 data to determine the minimum number samples needed to detect a significant difference in the number of bivalves in adjacent quadrats (Sokal and Rohlf 1981, see page 262-263). For more accurate characterization of the population size, 26 quadrats of steamers, 41 of quahogs and 1380 of mussels would be needed.

Table 3. Average number of bivalves per square meter

Bivalve	Restricted marsh 1997 (ind./m^2)	Restricted marsh 1999 (ind./m^2)	Unrestricted marsh 1997 (ind./m^2)
Quahog	5.2	6.4	1.1
Blue mussel	0	1.1	65.1
Steamer clam	0.7	5.5	0.7
Total area sampled (m^2)	3.75	6.75	3.75
Number of quadrats	15	27	15

collected			

Summary

The sampling conducted in 1999 gives a qualitative snapshot of the present state and distribution of the commercially important bivalves in Hatches Harbor. In the subsequent years, we can use bivalve population sampling to document the effect of salt marsh restoration project on bivalve populations in the restricted marsh.

Fecal Coliform Sampling

The Seashore confers with the DMF to evaluate the possible relation of fecal coliform levels to the events associated with salt marsh restoration activities as the shellfish beds in the unrestricted marsh are periodically harvested for seed clams. The coliform data will allow the Park to coordinate the periodic culvert openings with harvesting activities in the marsh and minimize adverse effects.

The Massachusetts Division of Marine Fisheries (DMF) performed fecal coliform sampling. It is done periodically to measure background coliform levels, estimate seasonal variability and gauge coliform levels in relation to shellfishing activities in the Hatches Harbor (G. Heufelder, personal communication).

Methods

Fecal coliform samples were collected in the unrestricted marsh at two sites – one adjacent to the dike culverts and one in the interior of the marsh by the DMF according to the methods employed by the Barnstable County Department of Health and Environment (APHA 1992). The water samples were collected and analyzed at the Barnstable County Department of Health where the Fecal Coliform MPN method was employed to estimate coliform counts. Sampling was performed at least once per season. Thanks are given to J. Moles for contributing his data for this report.

Results/Conclusion

Fecal coliform levels displayed a seasonal summer peak as warmer temperatures cause bacterial growth and increase wildlife activities in the marsh basin (Figure 9). These levels drop in the winter below EPA standard levels before beginning to rise before the next summer. The June 1999 levels at the station adjacent to the dike are much higher than those at the station in the interior of the marsh and may represent the higher tidal exchange rates due to the new culvert configuration as of May 25th, 1999. Fecal coliform levels in August 1999 are half what they were at the same time in 1998. One could speculate that the new culvert configuration allowed a greater flushing and dewatering of the restricted marsh at ebb tide thus contributing to a lower coliform level some time after the marsh establishes a new tidal exchange equilibrium. However, there was a 40-year drought in 1999 and the lower coliform levels or other factors to be determined may simply reflect this. Each new culvert opening may cause a short-term increase in background coliform levels as the new tidal regime floods marsh surfaces that have not been inundated regularly for decades. However, the culvert configuration allows greater ebb tide drainage, so such a coliform increase is probably a transient event. Increased tidal velocities should flush organic matter from channels near the dike leading to less favorable conditions for bacterial survival. Future coliform data will help us gain a better understanding of the relationship between tidal exchange and coliform levels in the restoring marsh.

General Conclusions

With increased culvert openings, spring tidal range has increased by over 20%. The tidal stage record also shows that the new culverts greatly limit water levels in the restricted marsh during conditions that increase high tides above mean spring tide levels. During an astronomical spring tide, the new culvert configuration allowed only 16-20% of the tidal heights in excess of average spring tides found in the unrestricted marsh.

The new culvert cross-sectional area also allows more complete drainage of the marsh during ebb tide altering morning and evening tidal exchange and the restricted marsh hydroperiod. As a result of higher tidal range and lower low tides, seawater is penetrating about 20 m further into the marsh, favoring re-establishment of salt marsh grasses and allowing allow fish access to the wetland surface, increasing feeding pressure on floodwater mosquito larvae.

Average low tides are lower; causing reduced low-tide porewater levels even during spring tides. This allows increased root zone aeration and improving conditions for salt marsh plant growth. Sulfide, a product of anaerobic decomposition in waterlogged peat, remains very low in wetland root zones. In addition, lower low tides enhance drainage and reduce ponding along the Airport approach. Lower low tides reduce floodwater mosquito breeding.

Salt marsh mosquitoes have not increased, in either absolute or relative abundance, since restoration began. Good baseline data have been collected for evaluating impacts of restoration on bivalve populations in the restricted marsh; however shellfish harvesting makes it difficult to evaluate populations in the unrestricted marsh. Coliform data collected by the DMF implied an initial increase in coliform levels followed by a decline in coliform levels three months later. However, infrequent sampling and the 40-year drought confound ready interpretation of these coliform level trends.

2000 Future monitoring and research projects

This summer, a joint project will be conducted by CCNS, NPS staff members in partnership with USGS and University of Rhode Island researchers. We will employ a number of field and laboratory techniques to characterize vegetation cover and salt marsh development processes in the Hatches Harbor basin. CCNS and NPS researchers will resample 193 vegetation plots first established in 1997. Vegetation cover will be measured by the point-intercept method. In addition, a complete series of aerial photographs will be taken to allow CCNS resource management staff to monitor vegetation changes above and below the dike. Along with the vegetation plot data, these photographs will allow us to use GIS to directly compare changes in vegetation cover employing ArcView and ArcInfo.

The second component of this study will characterize salt marsh development in Hatches Harbor. During the summer and fall of 2000, URI and USGS researchers will measure sedimentation and accumulation rates in *Spartina* and *Phragmites* stands in both marshes using radiometric dating techniques, estimating accumulation rates and identification of significant horizons in the marsh peat layers. In addition to understanding current responses of the marsh to sea level rise and tidal restoration, it is equally important to document the recent history of salt marsh development at Hatches Harbor from natural unrestricted marsh habitat, to restricted degraded marsh habitat (beginning in 1930) and back to an unrestricted restoring marsh.

Finally, Seashore and NPS will continue to monitor tidal stage, water column environmental parameters, pore water chemistry and water table level, mosquito populations and bird populations as a part of our ongoing environmental monitoring at Hatches Harbor during the restoration process.

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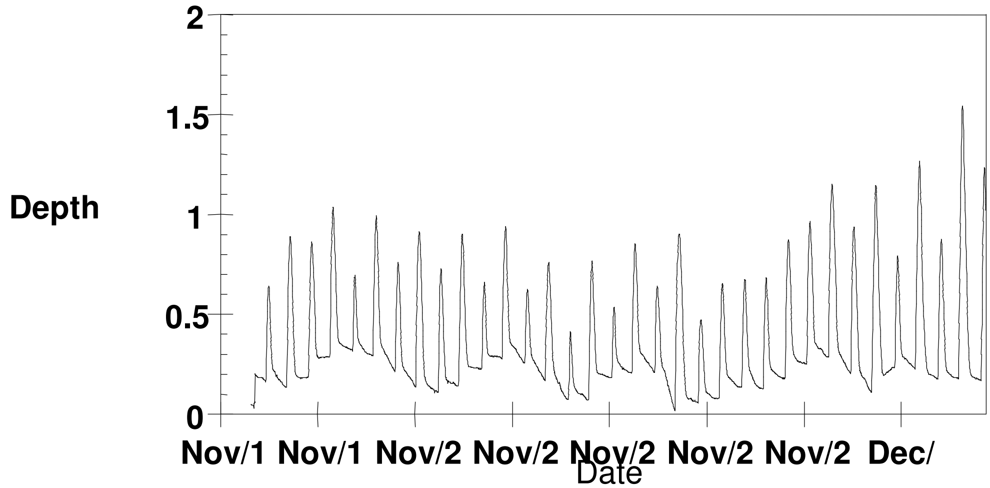
Tide stage - unrestricted marsh
Nov 16 to Dec 4 1998



Tide stage - restricted marsh
Nov 16 to Dec 4 1998

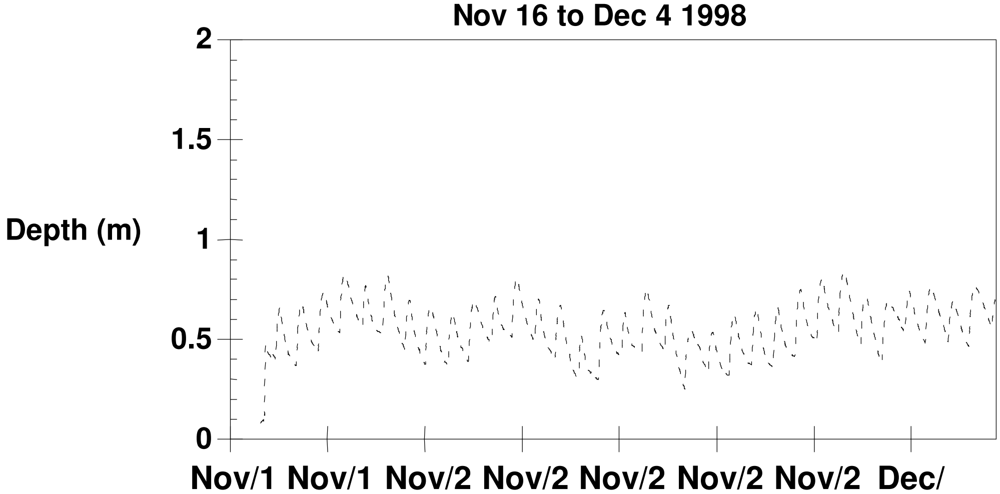
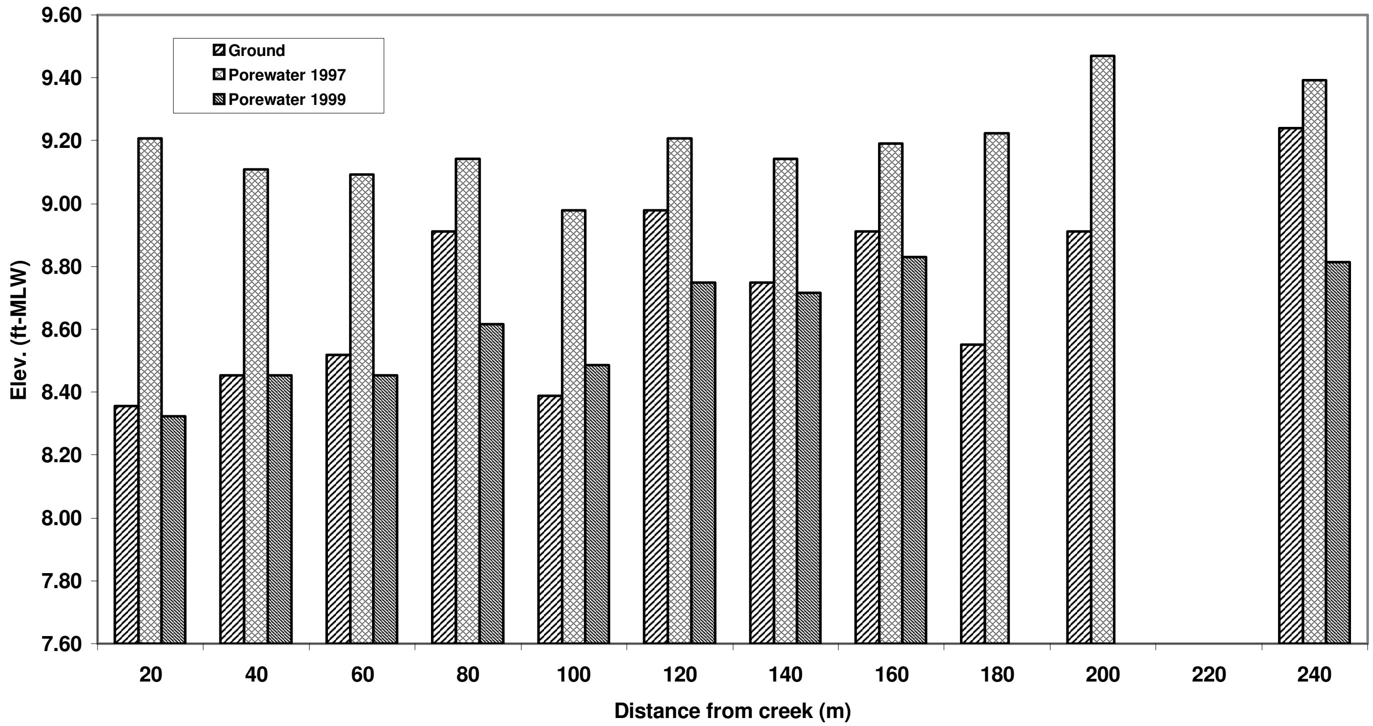
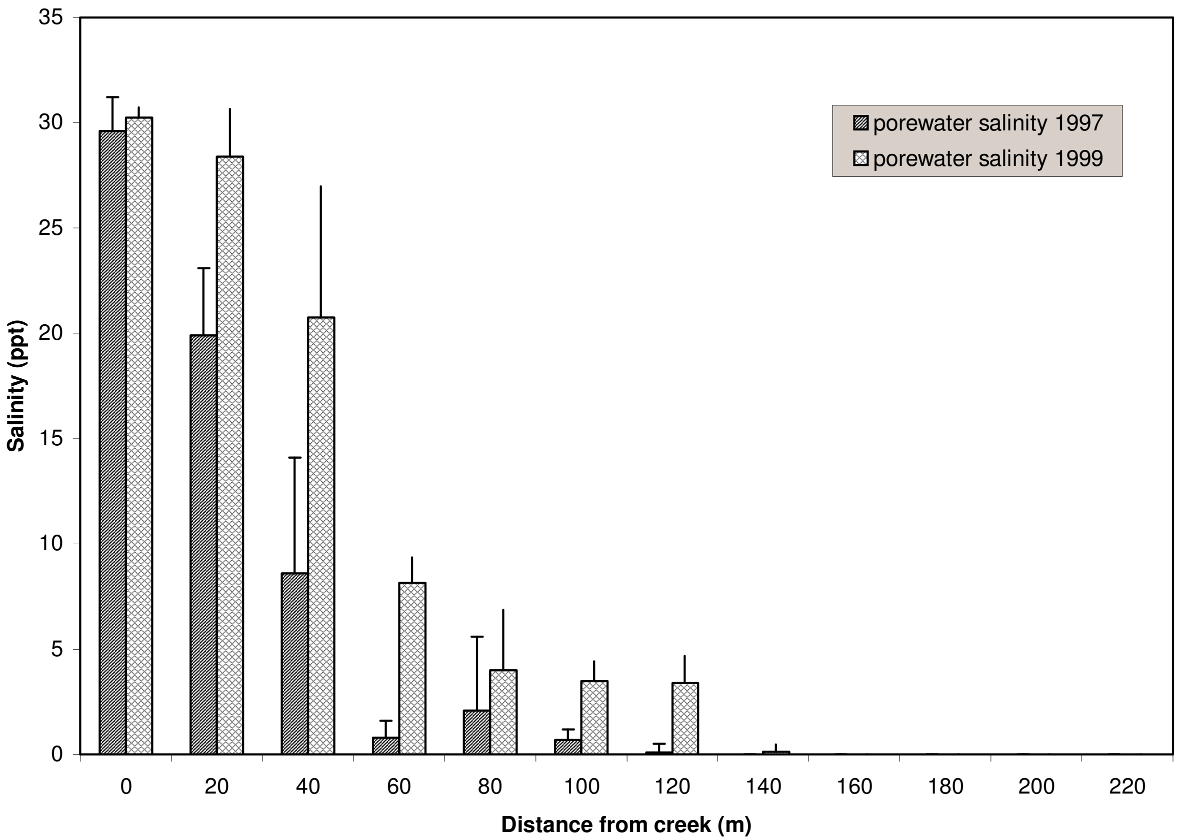


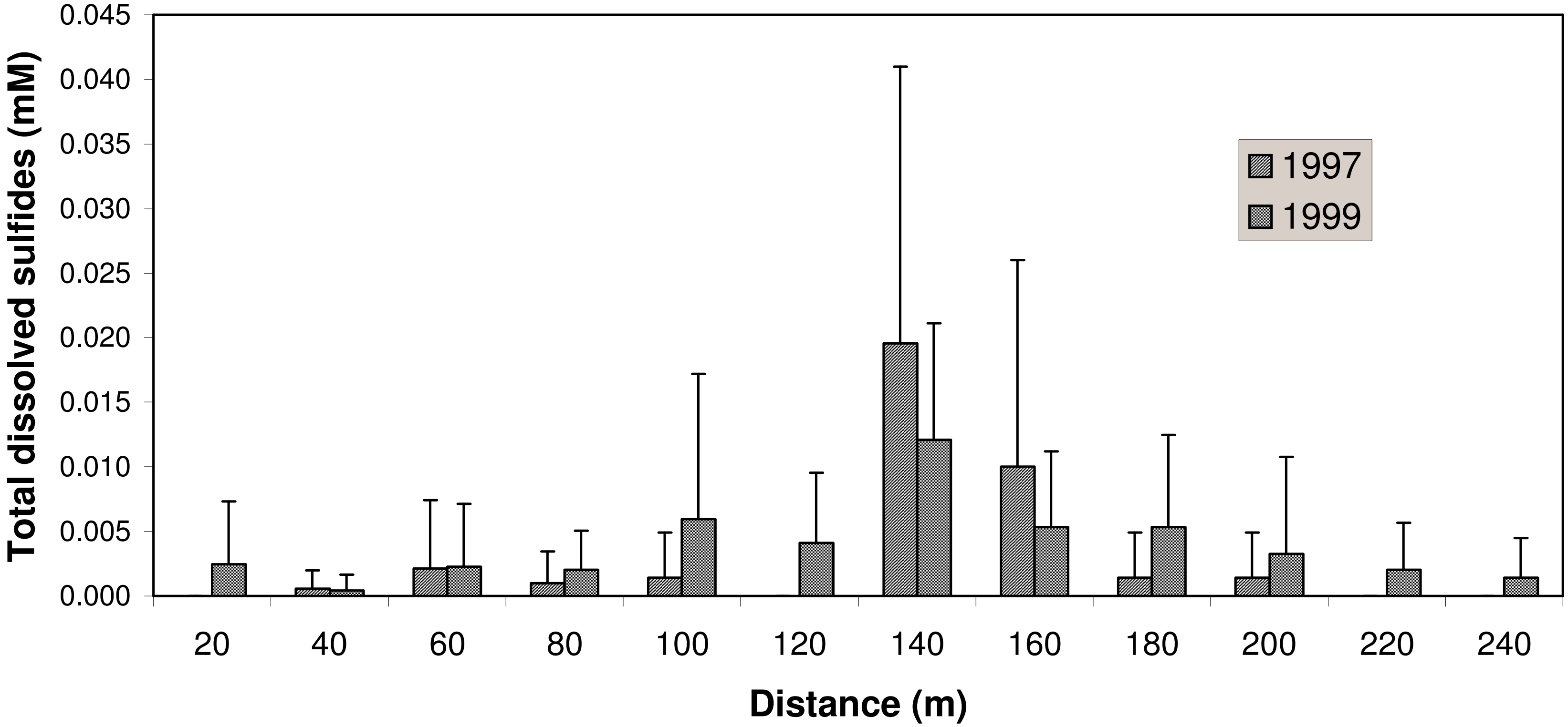
Figure 5. Water table elevations in the restricted marsh
Before and after dike opening

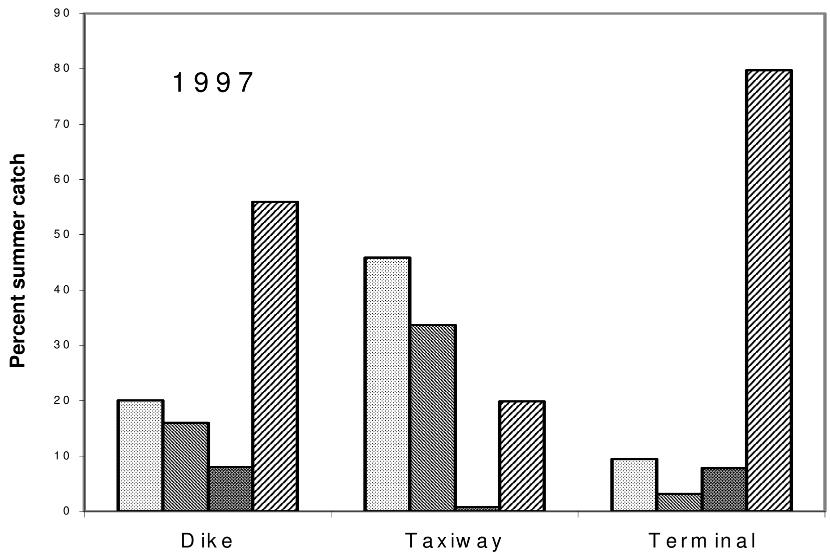


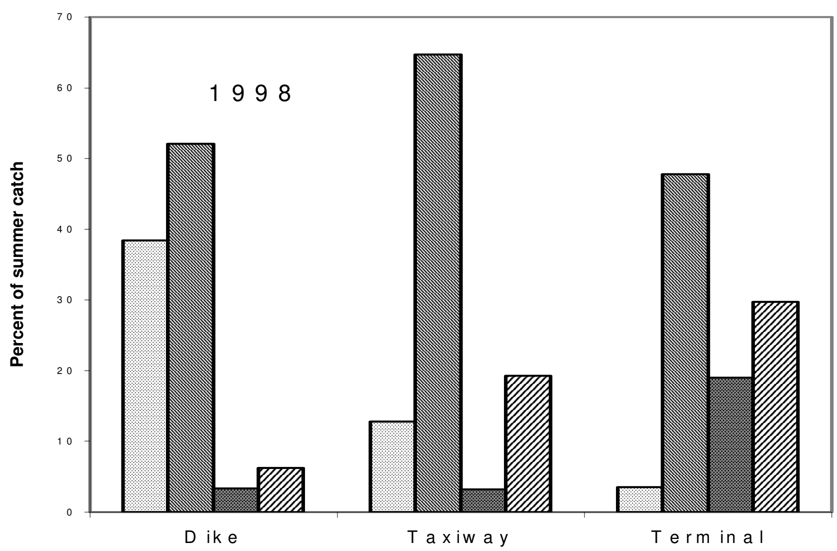


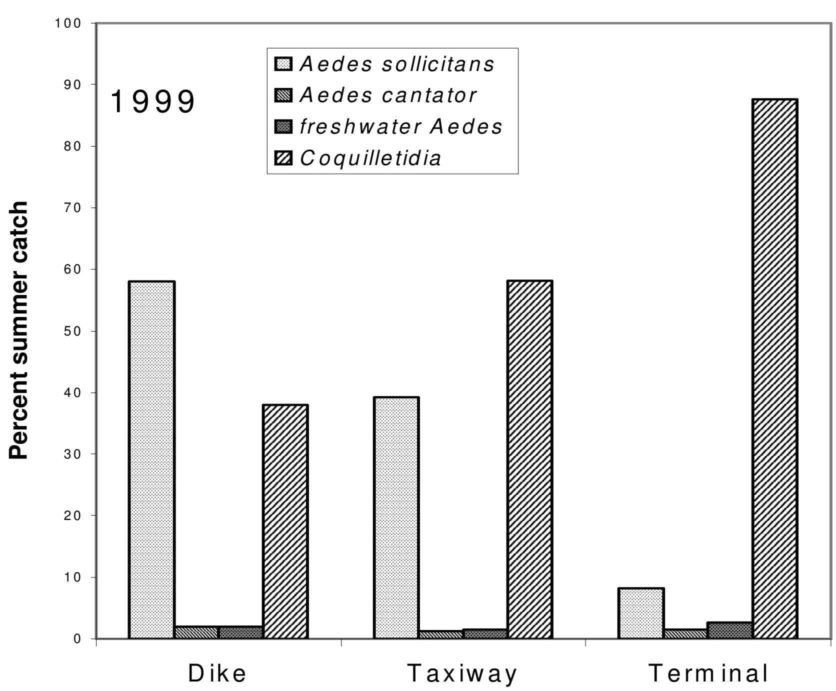
35
30
25
20
15
10
5
0
Salinity (ppt)
porewater salinity 1997
porewater salinity 1999
0
20
40
60
80
100
120
140
160
180
200
220
Distance from creek (m)

Porewater sulfides above the dike: spring-neap tidal mean and SD




1997
Percent summer catch
0
10
20
30
40
50
60
70
80
90
Dike
Taxiway
Terminal


1998
Percent of summer catch
0
10
20
30
40
50
60
70
Dike
Taxiway
Terminal


1999
Percent summer catch
Aedes sollicitans
Aedes cantator
freshwater Aedes
Coquilletidia
0
10
20
30
40
50
60
70
80
90
100
Dike
Taxiway
Terminal